HTS INDUCTIVE ENERGY CHARGING & DISCHARGING CIRCUIT & ITS APPLICATION IN THE DESIGN OF SMES UPS

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HTS INDUCTIVE ENERGY CHARGING & DISCHARGING CIRCUIT & ITS APPLICATION IN THE DESIGN OF SMES UPS

A Thesis Submitted In the Partial Fulfillment of the Requirements for the Degree Of

Master of Technology
In
Electrical Engineering
By

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Under the Guidance of

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CERTIFICATE

This is to certify that the Thesis Report entitled "**HTS INDUCTIVE ENERGY CHARGING & DISCHARGING & ITS APPLICATION IN THE DESIGN OF SMES UPS**", submitted by **VINIT KUMAR SUMAN** bearing roll no 213ME5461 in partial fulfillment of the requirement of the award of Master of Technology in Electrical Engineering with specialization in "cryogenics and vacuum" during session 2013-2015 at National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

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ABSTRACT

In this era of high technological development, energy storage devices are one of the prime requirements. More and more focus is on designing efficient energy storage systems. One of the highly efficient energy storage systems is Superconducting Magnetic Energy Storage system. It is a magnetic field based direct energy storage system. It stores the required energy in the magnetic field with almost zero loss. A SMES system consist of four parts - the superconducting coil (SC),the power conditioning system (PCS), the cryogenically cooled refrigerator (CS) or the cryogenic system and the cooling unit (CU). Since superconductors practically offer almost no resistance to current flow, energy can be stored indefinitely in the magnetic field owing to the reason that the direct current will not decay once the coil is charged. The stored energy can be supplied to the network by discharging the same coil. The present work basically deals with the study of various energy storage systems and comparing their performance and control characteristics. Also detailed modelling of the charging and discharging SMES circuit on different inductance and reference voltage values has been done. The reliability of the HTS inductors in the field of electrical design has been presented. In the present work, the aim is to build SMES UPS (Uninterruptible power source) so as to store energy for longer periods. The design is done using SIMULINK/MATLAB.

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CHAPTER 1

1. INTRODUCTION
2. LITERATURE REVIEW
3. THESIS OBJECTIVE

1.1 INTRODUCTION

The concept of Superconducting Magnetic Energy Storage (SMES) was developed in a superconducting coil and store energy in its magnetic field with essentially zero losses. However by implementing this principle efficiently and economically has proven to be quite challenging for Research and Development. Development of various technologies has severely limited the wide spread use and acceptance of SMES. They include the superconducting materials and manufacturing techniques, the cryogenic refrigeration systems and the power electronics.

The main advantage of the SMES devices compared to other devices are: (a) High energy storage density, (b) High energy Storage efficiency, (c) Long Application life time and (d) less environmental pollution.

In this project, It has been analyzed the HTS inductive energy of control charging and discharging characteristic and simulated using MATLAB which aims to study the practicality of SMES-UPS by introducing HTS Technology. And also it has been study various type of energy storage devices and its characteristics. Based on the simulation results and calculation done till today will help me in designing 3-phase SMES uninterruptible power system (UPS) simulation using SIMULINK/MATLAB.

1.2 LITERATURE REVIEW

J. I. S. Martin 2011 [1]: This paper is mainly deal with the main use of SMES lies in the energy storage. However, it can also used to meet other desirable purposes. The primary used of SMES is that it can improve power stability by reducing system oscillations and boosting system voltage stability and removing sag . SMES can offer spinning reserve, enhance FACTS performances, balance fluctuating load, lead to a decrease in the area control factor, can be used for levelling of load and balance power system asymmetries

H. P. Tiwari & S. K. Gupta 2010 [2]: This paper is mainly deal with the energy storage methods which can be classified as direct storage and indirect storage with further classifications as shown Most of the available energy storage techniques are included in this classification. The various storage methods and their working principles are discussed.

Jin, Xang et al 2007 [3]: This paper is concerned with the control of magnet energy storage and the release scheme. It is done in order to increase the stability of the inductor regarding the energy stored through it. In Cu coil inductor, the energy consumed or lost is quite high compared to the superconducting coil inductor is used to minimize the energy loss and store energy for much longer period of time. The practical approach towards the said superconducting coil inductor system is dealt in this paper. “A Power Inductor Energy Control Scheme”

Xiao-Yuan Chen et al 2008 [4]: This paper basically deals with the study and analysis of High Temperature Superconducting (HTS) power inductor and its control. In this paper work has been done using the MATLAB/Simulink so as to propose a controlled release scheme based on the results obtained and experiments performed. It is verified to develop a practical HTS SMES prototype. It is found that the due to the existing resistance common power inductor should not be used. Also it is very important to release energy in controlled manner.

Xiaoyuan Chen, jianxun Jin. Et al 2008 [5]: In this paper the energy charging and discharging characteristics have been analyzed theoretically. Detailed simulation models based on Matlab model as well as important calculation has been presented in the paper. This paper also deals with the quantitative and qualitative advantages of replacing Copper conductor with the SMES-HTS inductor. Its verification is done on MATLAB/SIMULINK. It is found that in practical SMES UPS application HTS inductor with almost zero resistance and high current density is more suitable to achieve high density energy storage with more energy storage time. To match certain discharging power proper control of the stored energy is preferable

1.3 THESIS OBJECTIVES

The Objectives to be achieved in this study:

1. Comparative study on the various energy storage method and its efficiency, response time, backup time, power density, energy density.

2. Modelling of charging and discharging SMES circuits by taking the value of different inductor and reference voltage and then, presenting the reliability of HTS inductors in the field of electrical design in the forthcoming years.

3. In this thesis work, the aim is to build SMES UPS (Uninterruptible power source) so as to store energy for longer periods. And to design a 3-phase SMES UPS and control circuit to make it really efficient for the near future.

CHAPTER 2

1. IMPORTANCE OF ENERGY STORAGE

2. COMPARISION

3. BASIC PRINCIPLE

2.1 IMPORTANCE OF ENERGY STORAGE AND A COMPARATIVE STUDY OF THE VARIOUS ENERGY STORAGE METHODS:

2.1.1 Different energy storage methods

To store energy physical device or storage medium is required. There are many examples of such storage methods are all around us.It can be further explained as artificial and natural storage mediums. Batteries and flywheels are examples of artificial energy storage mediums whereas fossil fuel and falling stream are some example of natural energy storage mediums.

Alternatively, energy storage methods can be classified as direct storage and indirect storage with further classifications as shown in Figure 2.1. Most of the available energy storage techniques are included in this classification.

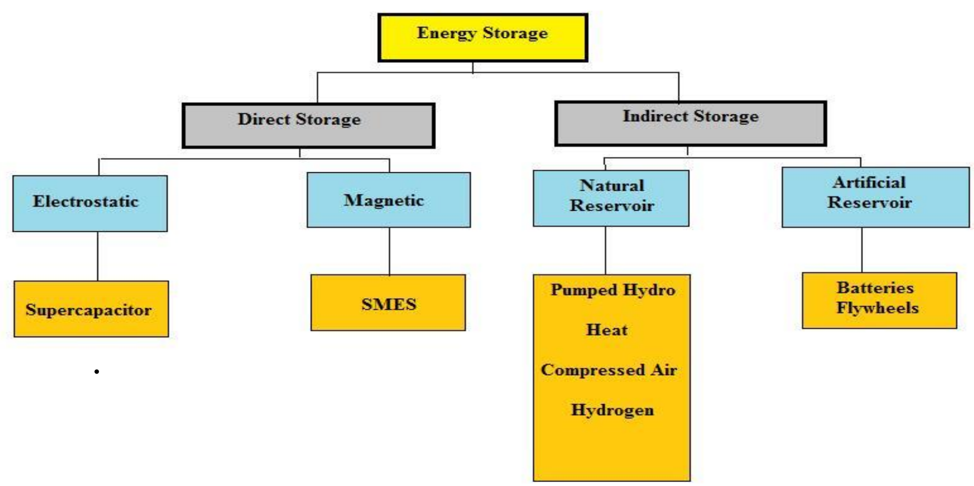


Fig 2.1 Classification of energy storage techniques [1]

2.2 COMPARISON OF VARIOUS ENERGY STORAGE METHOD

Serial no.	Parameter/ Figure of Merit	CAES	FES	PHES	BES	SCES	SMES
1.	Range	25-350 MW	Several kW	Up to 2.1 GW	20-100 MW	1-250 kW	1-100 MW
2.	Power Density (kW/ m^3)	More Than PHES	>707-1767	Depends on the available head	106-7067	176678	>530
3.	Energy Density (kW- h/m^3)	More Than PHES	>282.7-424	-	>70.7-247	>53	>7.07
4.	Emissions	No	No	No	Very low	No	No
5.	Electrical efficiency	~70%	90-95%	75-80%	88-92%	<95%	~95%
6.	Lifetime	<50year	10-20year	~50 year	3-6year	10-20year	~30year
7.	Response time	~1-2 Minute	~1-2 minute	~1-2 minute	second	millisecond	Millisecond
8.	Backup time	Hour	minute	day	Hour	second	Second

Table 2.1: Comparison of various energy storage methods [2]

2.2.1 Comparative study on the various energy storage methods

The Table 2.1 shows the comparative study of different figure of merit and parameters of the various energy storage methods and technologies. Energy storage method depends on the type of power system. For example whether power system is remote or near, interconnected network or independent system. In permanent type of application where low power required, Lithium-ion batteries can be preferred. Lead acid batteries might be used for electrical power systems up to a few kWh whereas large compressed air energy storage and flow battery technologies are usually utilized for a few MWh rated electrical systems. To ensure the power quality of the system super capacitors and flywheels are very useful. Pumped hydro energy storage is generally preferred in large scale systems whereas SMES is very useful in power applications ranging from 100 MW – 5000 MW. Also SMES system is quite appropriate for energy storage from intermittent resources.

2.2.2 Discussion

. The comparative study in section 2.2 reveals that the SMES has the highest efficiency and the lowest response time among all the energy storage systems. There is no problem of emission in this system. SMES simple working methodology is based on the charging and discharging of a superconducting coil that is refrigerated to maintain superconducting characteristics basically temperature, current density and magnetic field.

Electrical energy cannot be stored very easily and economically. Since 1980, the study of different types of superconductors, coil designs and protection schemes, necessary mechanical tests and different application of SMES in the power system are amongst the most important and valuable area of scientific research and development

2.3 BASIC PRINCIPLE OF SMES

A Superconducting Magnetic Energy Storage (SMES) system stores the energy in its magnetic field due to flow of direct current in a coil made of superconducting material (e.g. NbTi at 10K or YBCO 92K) which is cryogenically brought down to a temperature below its critical temperature so that it can behave superconductor using liquid He or liquid N2.

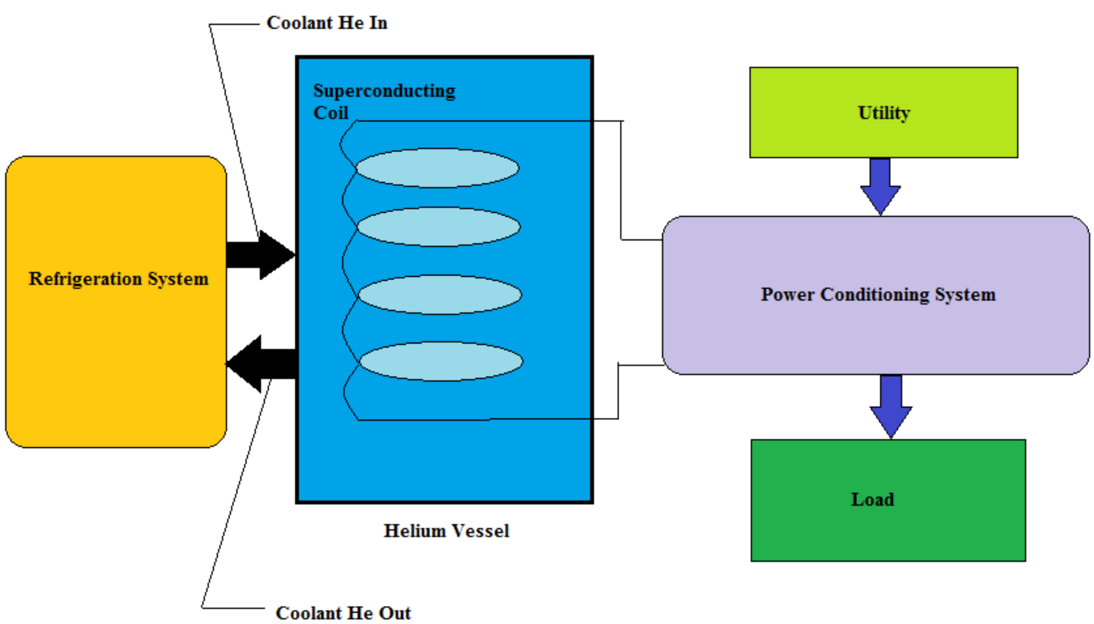


Fig 2.2: Figure showing basic principle of SMES [6]

A SMES system (Figure 2.2) consist of four parts - the superconducting coil (SC),the power conditioning system (PCS), the cryogenically cooled refrigerator (CS) or the cryogenic system and the cooling unit (CU). Since superconductors practically offer almost zero resistance to current flow, energy can be stored indefinitely time in the magnetic field knowing to the reason that the direct current will not decay once the coil is charged. The stored energy can be supplied to the network by discharging the same coil. The power conditioning system consist of an inverter or rectifier circuit to transform alternating current power to direct current or convert DC back to AC power.

Use of power electronics switches causes 2-5% energy loss. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy because in the other methods, energy conversion processes from electrical to mechanical (flywheel energy storage) or from electrical to chemical (batteries) takes place whereas in SMES electrical energy is directly stored in the magnetic field and there will be no any conversion of energy takes place so SMES systems are thus highly efficient.

CHAPTER 3

1. PROPOSED WORK DONE
2. CHARACTERISTICS OF SMES
3. CONCLUSION

3.1 PROPOSED WORK DONE

3.1.1 HTS INDUCTOR BEING CHARGED AND ENERGY STORED ACROSS IT

The various inductance values for the SMES coil can be used to study the charge and discharge performance of the SMES models. However, for this purpose a charge-discharge circuit with PWM control technique is to be used so that the power supplied by the SMES to the load should be controlled [3]. The charge-discharge circuit is designed with the help of MATLAB/Simulink

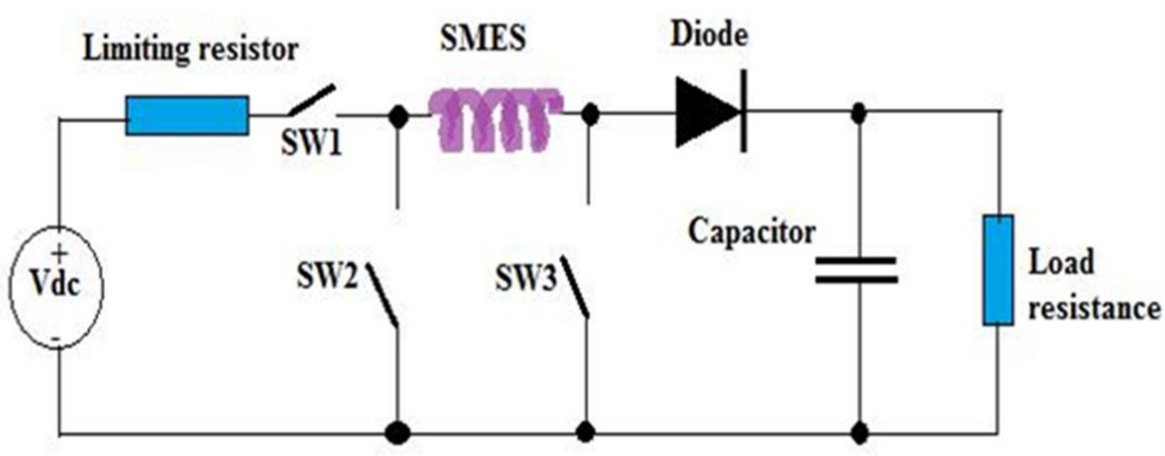


Fig 3.1 Circuit model of charge and discharge of SMES [3]

The charge-discharge circuit model for the study of the individual discharge performances of the SMES models is shown in Figure 3.1.

From the fig 3.1 it can be shown that the SMES starts charging when the switches SW1 and SW3 are on .When the charging process is complete the SMES operated in the purely energy storing mode by opening SW1 and closing SW2. However, for proper simulation purpose and to avoid inductive sparks at the switches SW2 should be closed first and then SW1 should be opened. Finally, for discharge purpose SW3 is opened so that the DC link capacitor may get charged and provide this power to the load.

The controlling of power flow such that when V_{ref} is greater than V_{load} SMES will be charged and when V_{ref} is less than V_{load} SMES will be discharge.

Modeling of the charge-discharge circuit for the SMES is executed using MATLAB/Simulink. The circuit is implemented for a purely resistive load. The ideal switch block with on-state resistance have been used in place of the switches. The various circuit components have been taken from different sections of the Simulink Library Browser like commonly used blocks, logic and bit operations, sinks and sources and Sim Power System.

The SMES is a pure inductance branch with the associated switches having very small but finite resistance values. The necessary logic operations and PWM control required are used to control switching actions. The charging of SMES is done for 1 sec.

Also, an L-C (inductance-capacitance) filter is used to reduce the ripples content .To avoid shorting of the source voltage a current limiting resistor r1 has been introduced into the circuit. C_f is the dc link capacitor. The load resistance under consideration can be the equivalent resistance of several parallel loads supplied by the SMES. Terminators are used wherever the output is not required. The diodes D1 and D2 are the freewheeling diodes.

For PWM control a voltage from the DC link capacitor as a function of time should be generated and this is done by implementing the subtracting block, Vref, PI block and the saturation block. This pulse is compared with the carrier sawtooth pulse generated by the Sawtooth Generator with a certain frequency. Thus, the pulse width modulation is obtained for power release control. The values for kp and ki have been selected. The subsystem for PWM generator is shown below in Figure 3.3 .It consist of input voltage and reference sawtooth pulse and a comparator. The frequency has been set to 50 kHz.

The simulation has been done using variable step ode-45 option of the Configuration Parameters section of the simulation window.

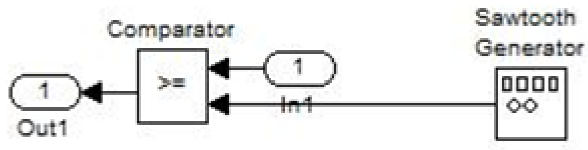


Fig3.3: Internal circuitry of PWM converter.

The solver option of the continuous powergui block is set to discrete mode and the time step is set to 0.0005 second. Such a circuit can be used to study charging and discharging performance of the SMES models and is discussed in the subsequent section.

3.1.2 MATHMATICAL EXPLANATION OF THE ABOVE SIMULINK MODEL

1. The energy stored across an inductor is expressed by following equation:

$$E = \frac{1}{2} L I^2$$

Where, L is the inductance I is the charging current

2. We have initially assumed a ZSR state (zero state response) i.e. that is the Initial current is

3. As, stored energy is given (i.e. the amount of energy that is to be stored in the magnetic field of inductor) which is taken as 5KJ.So, initial current equation is given as,

$$I_0 = \sqrt{\frac{2E(t)}{L}}$$

4. In, the charging process current is given by following equation,

$$i(t) = I_0\left(1 - \exp\left(-\frac{R_e t}{L}\right)\right) E = \frac{1}{2} L i(t)_0^2$$

5. Residual energy is defined as the difference in the initially stored energy and at any time till input source is applied.

6. Consumed energy is defined as the difference between the stored energy and Residual energy.

3.1.4 ENERGY DISCHARGING ANALYSIS

1. By assuming the initial state of current across inductor after input supply has been removed is I_0, now stored current will decay with time and its equation regarding this will be,

$$E_2(t_2) = \frac{1}{2} L\left(I_0\left(\exp\left(-\frac{R_e t_2}{L}\right)\right)^2\right) i(t) = I_0\left(\exp\left(-\frac{R_e t}{L}\right)\right)$$

2. Now, the consumed energy by the inductor is given by,

Q (t) =initial stored energy at any time t;

So

$$E(t) = \frac{1}{2} L\left(I_0\left(1 - \exp\left(-\frac{R_e t}{L}\right)\right)^2 \right)$$

3. Now, the inductor can be discharged with a constant power P0 (=U_p*I_p), thus the residual energy at any time t is defined as,

$$E(t) = E - P_0(t) - Q_3(t)$$

4. Consumed energy in terms of the HTS inductor with the resistance Re,

$$Q(t) = \int i(t)^2 R_e dt$$

5. Similarly, residual current through the inductor is expressed as,

$$i(t) = \sqrt{\frac{2[E - P_0(t) - Q_3(t)]}{L}}$$

6. Load current is given by,

$$i(t) = I_p = \frac{P_0}{U_p}$$

7. The equation relating effective power and total usage power,

$$\eta = \frac{P_0 t_s}{E} X100 \eta_t = \frac{P_0 t_s + Q(t)}{E} X100$$

3.2 CHARACHTERISTIC OF SMES

The discharge characteristics for the hybrid coil SMES coil for discharge voltages of 120V and a load resistance of 0.1 ohm are shown in Figure 5.5respectively. The discharge times for the respective voltages are 0.025s .The time of discharge decreases as the square of the discharge voltage.

3.3 Discussion

Thus, it is observed that if the discharge voltage is increased for a fixed resistance, the time of discharge decreases as the square of the discharge voltage. Also, it is evident from the above simulations that time of discharge increases with inductance of the SMES coil.

The SMES model that is used to fit for UPS application can now be chosen based on maximum time of discharge. Hence, the hybrid coil SMES coil is the best amongst the options.

CHAPTER 4

1. PREFERENCE OF SMES OVER COPPER COIL

2. CLOSED LOOP BOOST CONVERTER

4.1 PREFERENCE OF SMES OVER COPPER COIL

REASON FOR CHOOSING HTS IN PLACE OF CHEAP COPPER WIRE?

1 By formula we can see that as discharge time increases the discharge energy is decreases and vice versa

2. Thus, HTS inductor with larger stored energy value or the load with smaller power is favorable for obtaining longer discharging time and UPS application.

3. The total energy usage efficiency becomes higher while E increases or P_0 decreases.

4. A general ups stores energy for not more than a day but now this time it can be increased, so this is the advantage of HTS.

4.2 CLOSED LOOP BOOST CONVERTER

4.2.1 INTRODUCTION

There are two modes of operation of a boost converter. They are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation. During charging mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying .The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor. In the discharge mode of operation; the switch is open and the diode is forward biased. The Inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation [7].

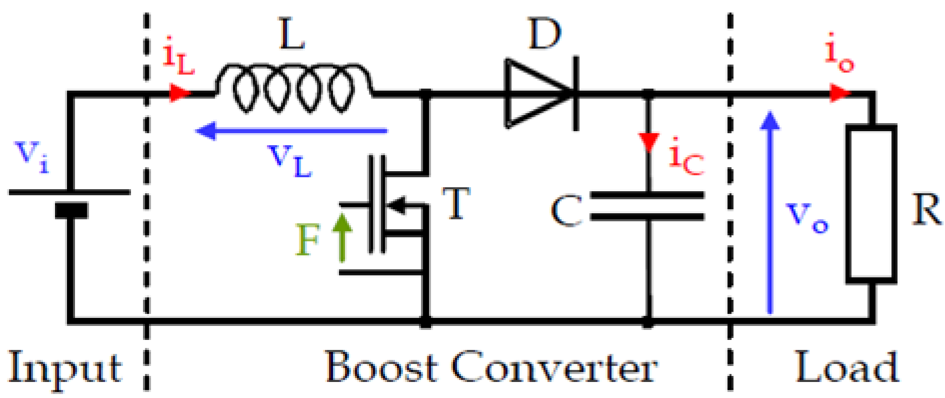


Fig4.1: Circuit of Boost converter

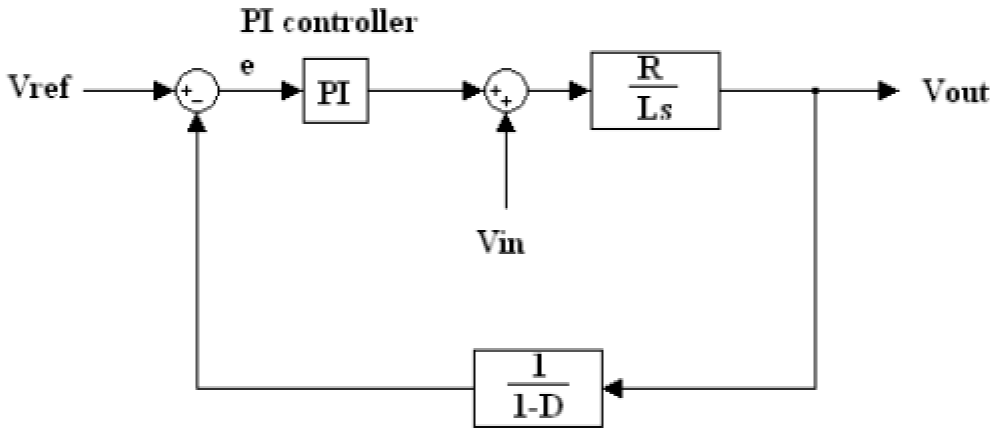
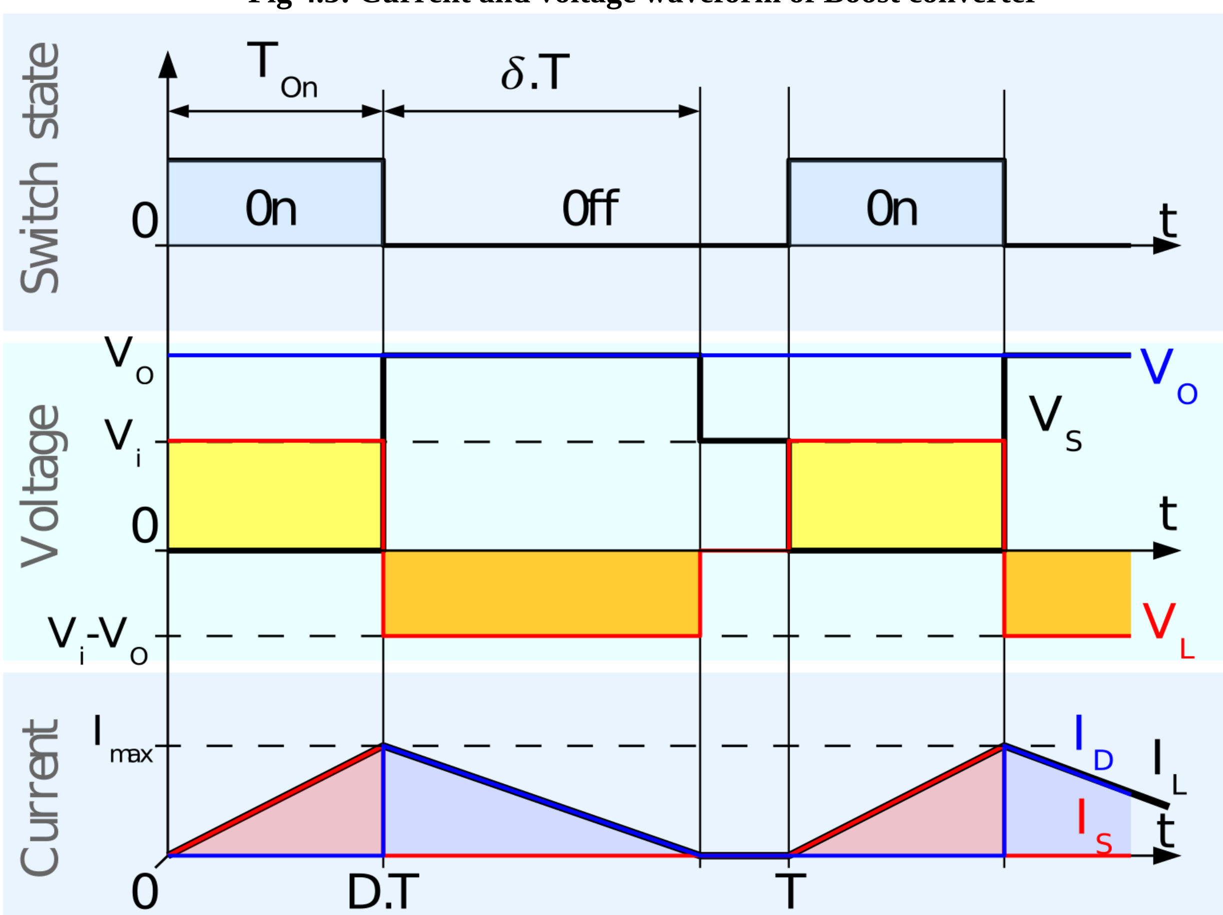


Fig 4.2: Block diagram of boost converter

Fig 4.3: Current and voltage waveform of Boost converter



4.2.2 DIFFERENT MODE OF BOOST CONVERTER

Mode 1 begins when IGBT's is switched on at $t = 0$ and continue up to at $t = t_{on}$. The equivalent circuit for the model is shown in Fig 4.1The inductor current $I_L(t)$ greater than zero and increases linearly. The inductor voltage is V_i

Mode 2 begins when IGBT's is switched off at $t = t_{on}$ and continue up to at $t = t_s$. The inductor current decrease until the IGBT's is turned on again during the next cycle. The voltage across the inductor in this period is $V_{in} - V_{out}$. In steady state time integral of the inductor voltage over one time period must be zero

$$V_i * t_{on} + (V_i - V_o) * t_{off} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, V_i= input voltage

V_o=average output voltage

$$\frac{V_o}{V_i} = \frac{T_s}{t_{off}} = \frac{1}{1-D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where T_S =switching time

D = duty cycle

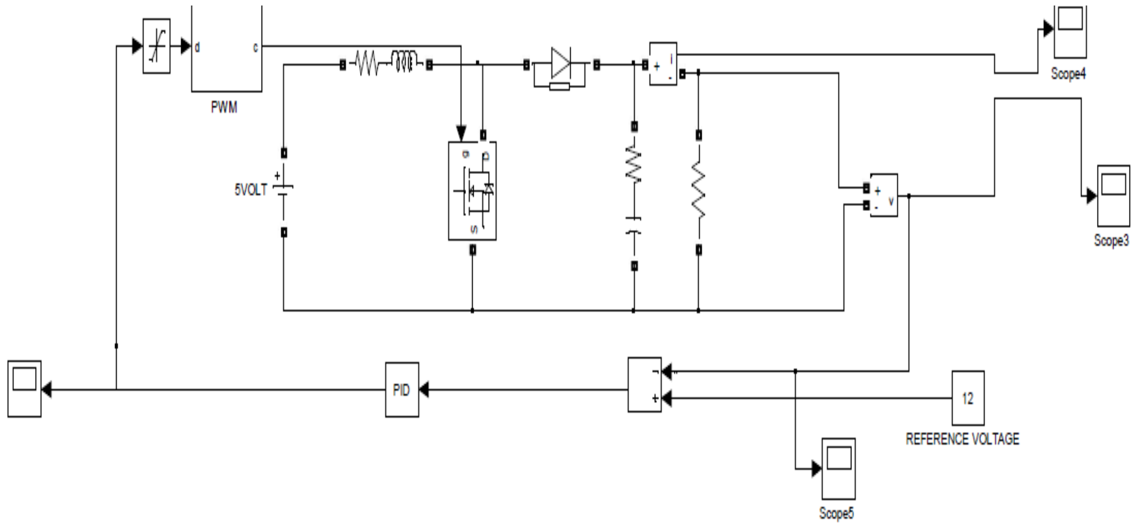


Fig 4.4: Circuitry of Boost Converter in MATLAB/ Simulink

Boost converter has been designed by taking the value of L=80uH and C=1.68uF R=80mohm V_{dc}=5Volt D=0.61where D is the duty cycle and fs=100KHZ and care has been taken so as to avoid the ripple factor associated with the circuit. As, we know that the capacitor block the DC and so all the ripple will pass through it and the DC voltage will appear across load that has resistance This circuit has a duty cycle of 61% and thus the output is nearly the twice of input and theoretically it is calculated by the formula which is also the nearly same that is V_{out}=12 volt.

CHAPTER 5

1.DESIGN OF UPS

2. CLOSED LOOP HYSTERESIS

VOLTAGE CONTROLLED INVERTER

5.1 DESIGN OF UPS

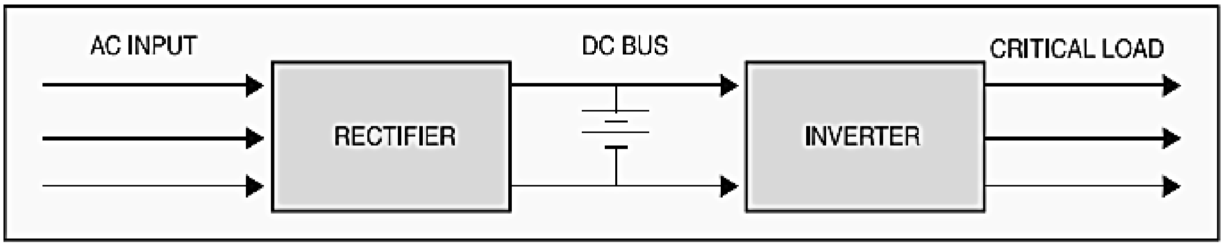


Fig 5.1: Design of ckt of UPS

1. Generally, we need to design the 3 phase rectifier and then 3 phase inverter and design of RLC FILTER at the load terminal for the inverter.

2. Rectifier converts AC to DC and it consist of filter which remove the ripple content.

3. And, from there we have to convert that dc to ac where actual critical load is connected.

5.2 CLOSED LOOP HYSTERESIS VOLTAGE CONTROLLED INVERTER

5.2.1 Introduction

There are so many linear and nonlinear control scheme .which are used to control the necessary physical quantity PWM techniques are widely used. According to this technique reference wave will be compared with carrier wave. For this purpose Hysteresis controller is used which can be easily executed and it is so simple also.

5.2.2 Block diagram

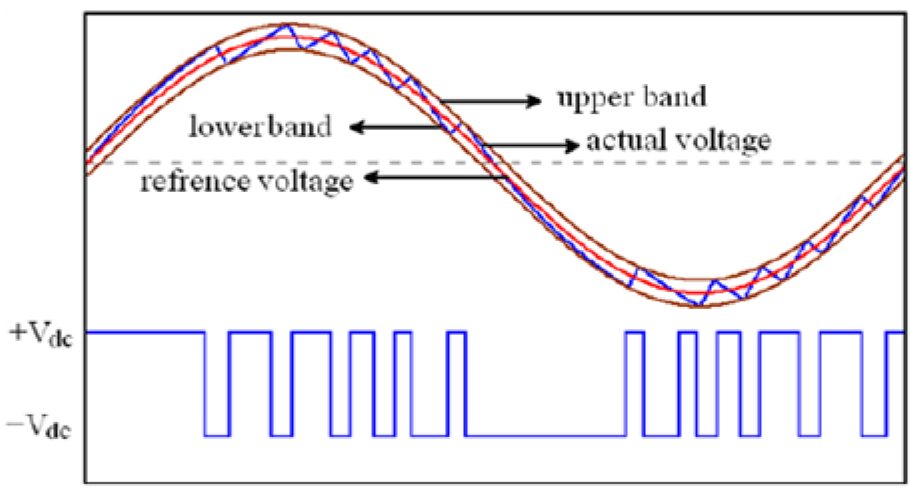


Fig 5.2(a) Waveform showing PWM technique

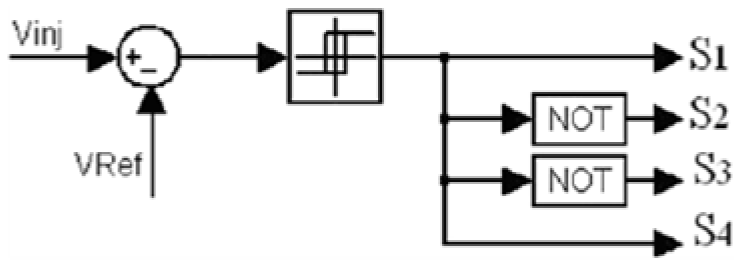


Fig 5.2(b) Control of switch

Hysteresis voltage-mode control is the simplest control method in the available method. The concept of operation is very simple. The switch is turned on, when the output voltage falls below minimum set point (i.e., lower boundary) value and turns off when output voltage is higher than maximum set point (i.e., upper boundary) value.

The controller does not use a compensation network, so the converter is able to react quickly to a transient event making it seem like a perfect solution for voltage regulator modules. However, the drawback of the voltage-mode hysteresis controller is its depend up on the converter's output capacitor.

5.3 DESIGN OF SMES UPS

5.3.1 Introduction

Uninterruptible power supplies (UPS) are used to supply power to different equipment during sudden power failures. Generator or any type of power supplying equipment operated during a power failure takes a few minute to few hour to respond. Since the discharge time of an SMES is generally of the order of few seconds so it is very suitable for UPS application.

but due to large cost of cryogenics system it can used as a UPS for powering a set of several computers (network) or workstation computers which can be treated as AC loads (a computer uses DC obtained after rectifying the AC by a switch mode power supply device or SMPS)[5]. In order to study its behavior as a UPS, it is connected across an AC load of rating 25kW, 380V R.M.S 50HZ.

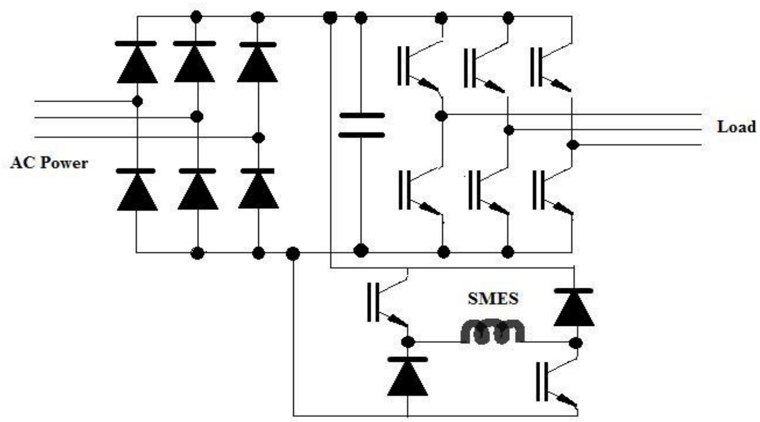


Fig 5.3: Block diagram of SMES UPS [5]

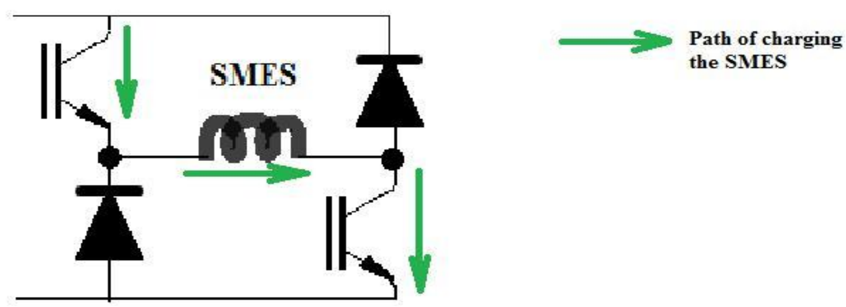


Fig 5.4 (a): Energy charging mode of operation [5]

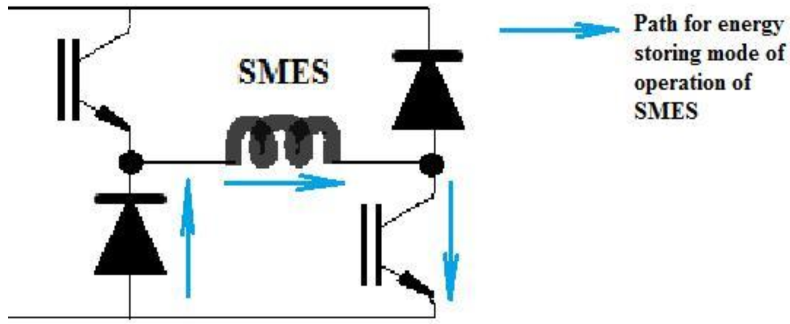


Fig 5.4(b): Energy storing mode of operation [5]

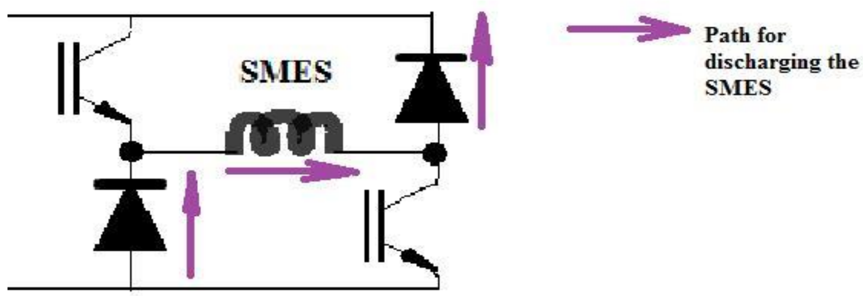


Fig 5.4(c): Energy discharging mode of operation [5]

Such a similar circuit for charge-discharge have already been used for simulation of discharge of a SMES. The charge-discharge circuit is now used to simulate the discharge of the hybrid coil SMES with a stored energy of 80 KJ. The total current is 400A and the inductance is 1H.

SMES charge-discharge circuit connected with AC load for UPS application using MATLAB/Simulink

The schematic diagram for an SMES UPS application using diodes and IGBTs is shown in Figure 5.3. The three phase AC power is rectified and given to the DC link capacitor connected with the SMES. The power release by the SMES is controlled by chopper control. By Using control techniques the chopper can be used to charge or discharge the SMES and different state of SMES is shown in Figure 5.4 (a) – (c) that is charging, storing and discharging of energy.

Since for the charge-discharge circuit this power flow is to be controlled using PWM control, it is done in MATLAB/Simulink using OR and NOT logic. However, ideal switches with a finite value of on state resistance have been used. Also, since an AC load is used in place of DC resistance for simulation, an inverter set with a discrete PWM generator block, a voltage regulator block and a three-phase L-C filter block has been used. The values of L and C for the filter blocks and the PI-constants are taken to reduce harmonic. These must have to be the values required to create minimum ripples. Finally, the simulation is done and the results obtained are discussed in the following section.

Simulation result

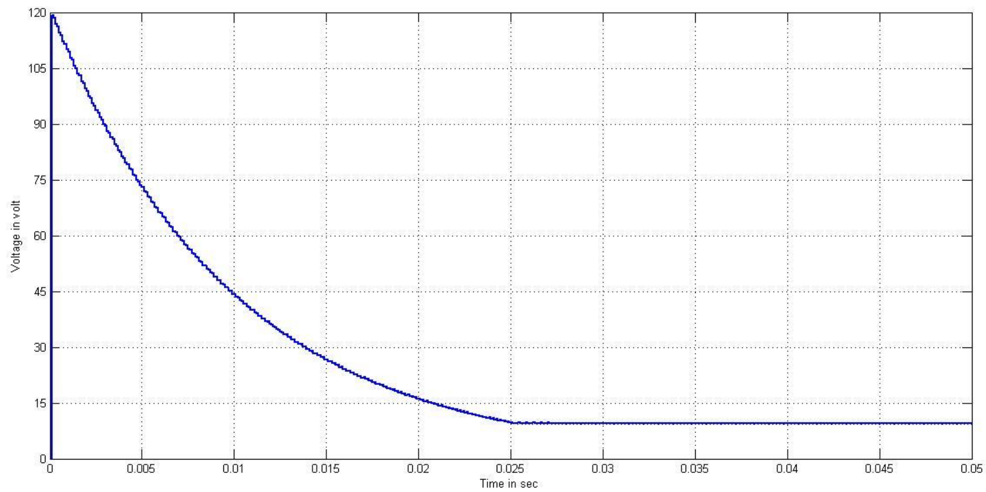


Fig 5.5: Discharging of SMES i=400 and L=1Hand V discharge=120volt

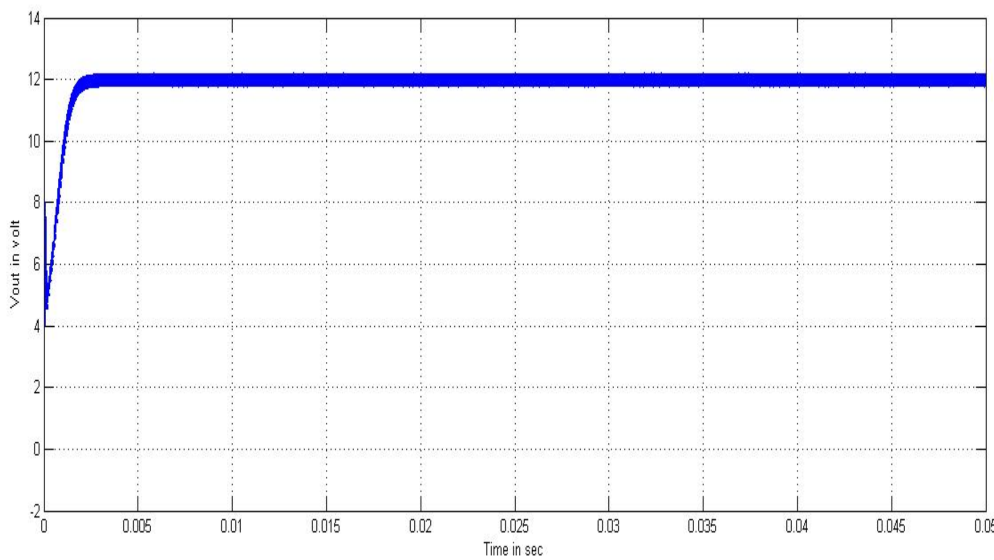


Fig 5.6 : Output voltage of closed loop boost converter

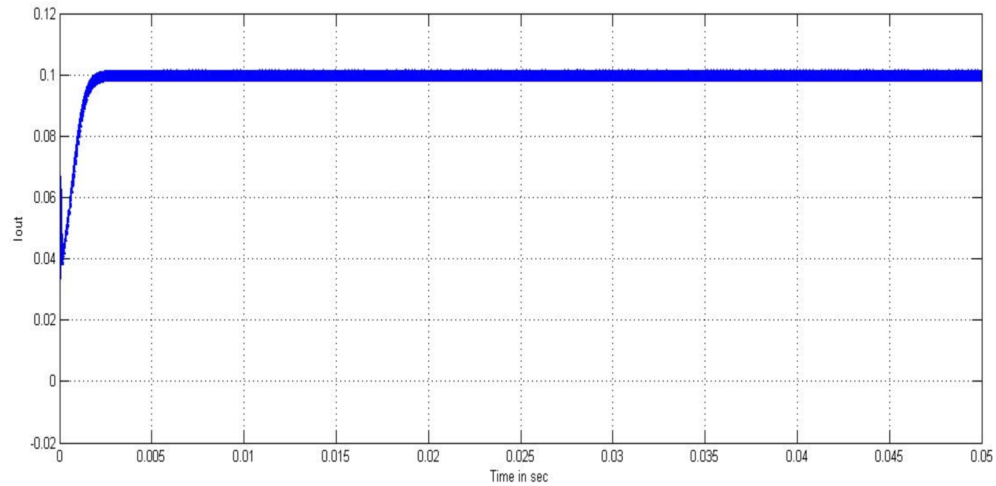


Fig 5.8: Output current of closed loop boost converter

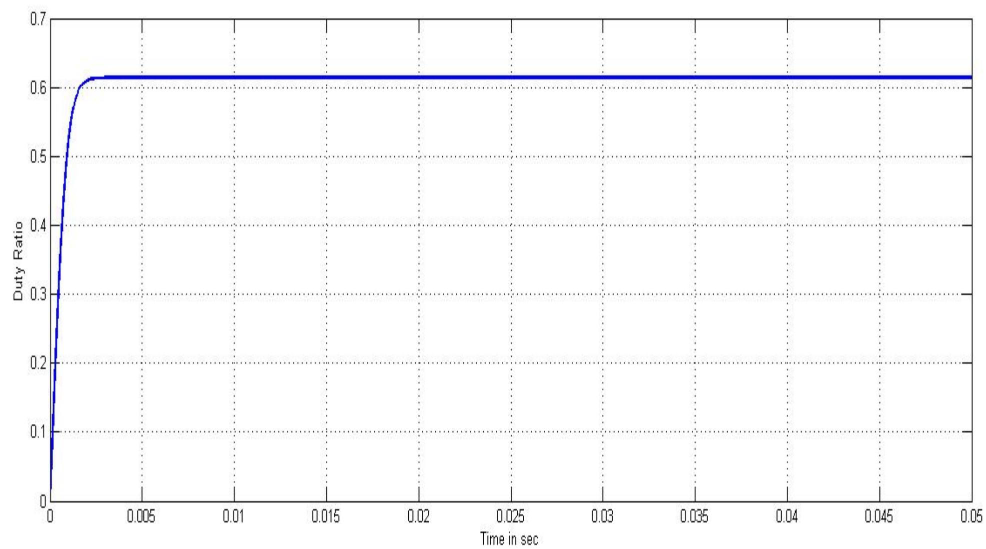


Fig 5.9: Duty Ratio of closed loop boost converter

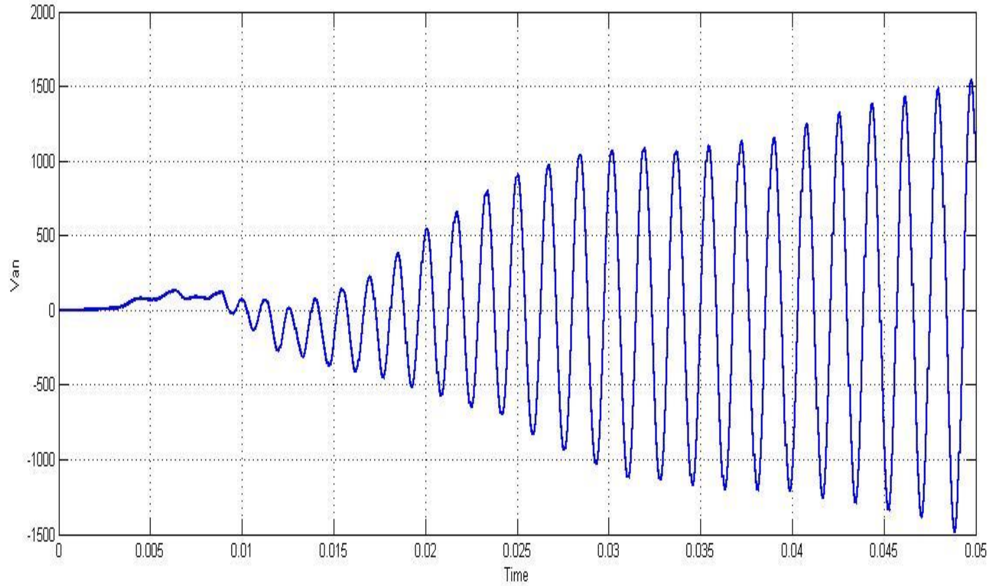


Fig 5.10 :Graph of Output voltage of closed loop hysterisas voltage controlled inverter across phase R

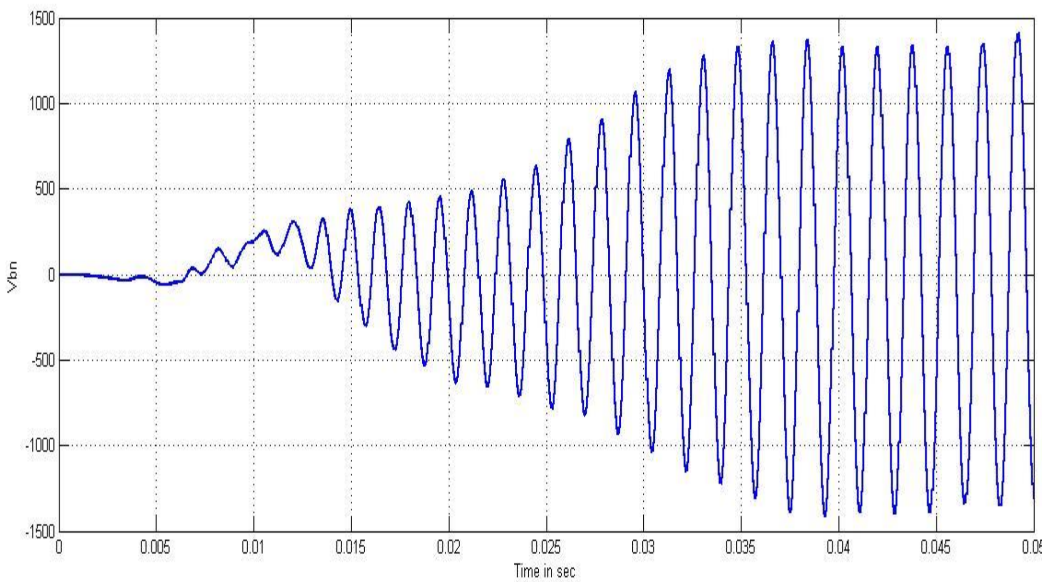


Fig 5.11: Graph ofOutput voltage of closed loop hysterisas voltage controlled inverter across phase Y

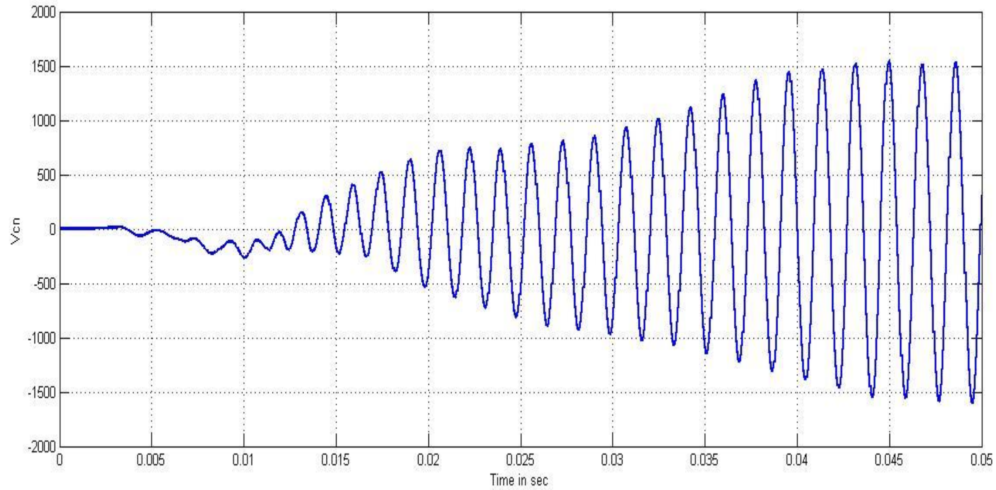


Fig 5.12: Graph of Output voltage of closed loop hysteresis voltage controoled inverter across phase B

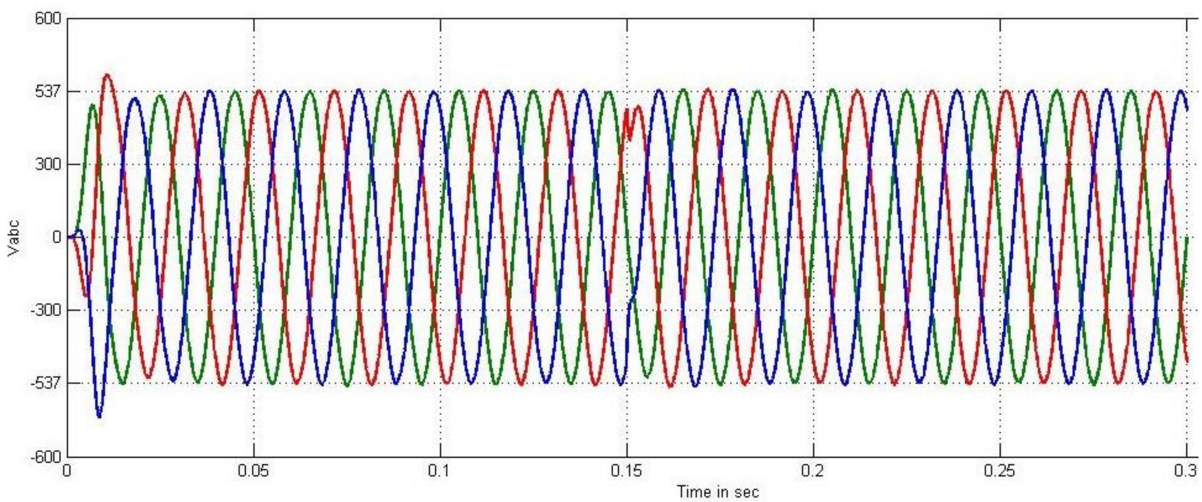


Fig 5.13: Graph of The simulated three phase voltage acrros load 25 KW in(volt) with time in sec

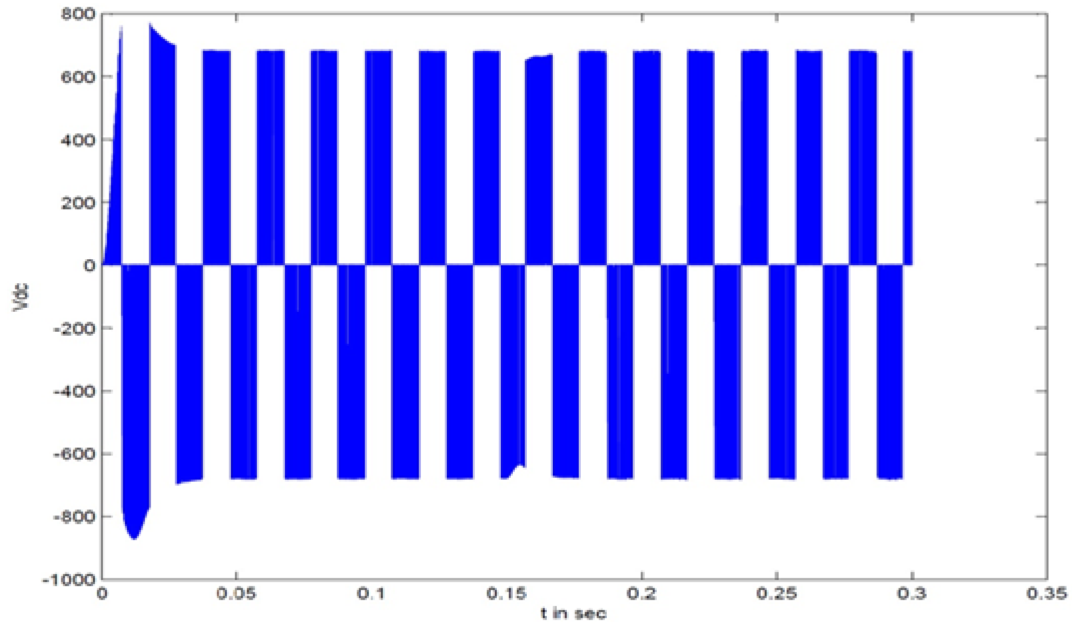
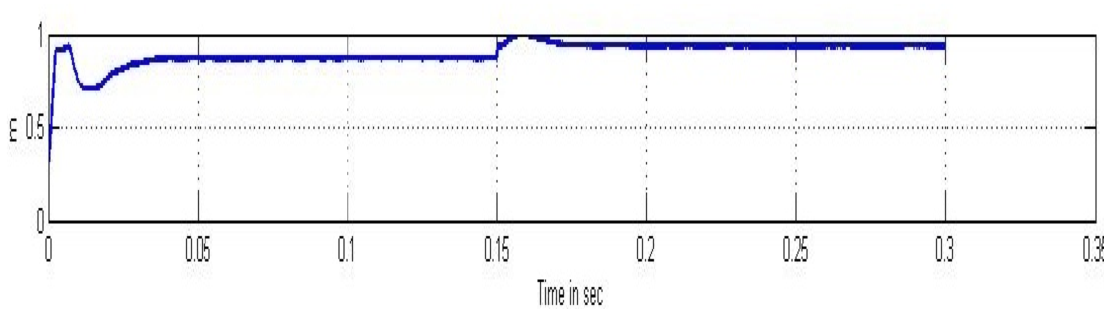


Fig 5.15: GRAPH OF VAB_INV (VOLT) VS TIME (SEC)



5.16: Graph of modulation index vs time (sec)

5.3.2 RESULT AND SIMULATION

Here, in the present analysis detailed application of SMES-UPS has been presented in order to study various aspects of HTS inductive energy storage technology .A UPS simulation model is built using Simulink so as to analyze the feasibility of the SMES-UPS, as shown in above Fig. 12. Here Pulse signals *S*1, *S*2 and PI controller are used to control the ON-OFF state of the IGBT switches. The values taken are

- HTS inductor L = 1 H,
- self-resistance of the HTS inductor
- *R*e = 0.002 ohm,
- Peak voltage value of the AC load V_{ab} = 537 V (380 Vrms).from graph
- In steady state, the effective value of the modulation index in the inverter is m =0.85
- the effective value of the DC voltage *V*dc = 778 V,
- ✓ So the fundamental component voltage *V*ab = 778 × 0.612 × 0.85=404 Vrms which is nearly the same value as it obtained from the simulation graph.

5.3.3 CONCLUSIONS

Conclusions can be made as follows:

- To achieve high density energy storage with longer energy storage time, HTS inductor having almost zero resistance and very high current density is preferred.
- The energy stored in the HTS inductor should be controlled to match with a certain discharging power and therefore high efficiency and large effective energy usage can be obtained.

5.4 REFERENCES

[1] J. I. S. Martin, I. Zamora, J. J. S. Martin, V. Aperribay & P. Eguia, Energy storage technologies for electric applications, *International Conference on Renewable Energies and Power Quality* (2011).

[2] H. P. Tiwari & S. K. Gupta, DC energy storage schemes for DVR voltage sag mitigation system, *International Journal of Computer Theory and Engineering*, **Volume 2(3)**, 1793-8201 (2010)

[3] J. X. Jin, Z. G. Wang, J. Wen, Y. G. Guo, and J. G. Zhu, "High temperature superconducting energy storage techniques," Journal of the Japan Society of Applied Electromagnetics and Mechanics, vol. 15, Supplement, pp. 108-111, Sept. 2007.

[4] A. Kawagoe, S. Tsukuda, F. Sumiyoshi, T. Mito, H. Chikaraishi, T. Baba, M. Yokota, H. Ogawa, T. Hemmi, R. Abe, A. Nakamura, K. Okumura, A. Kuge, and M. Iwakuma, "AC losses in a conduction cooled LTS pulse coil with stored energy of 1 MJ for UPS-SMES as protection from momentary voltage drops," IEEE Transactions on Applied Superconductivity, vol. 18, no. 2, pp. 783-786, June 2008.

[5] X. Y. Chen, J. X. Jin, K. M. Ma, J. Wen, Y. Xin, and W. Z. Gong, "High temperature superconducting magnetic energy storage and its power control technology," Journal of Electric Science and Technology of China, vol. 6, no. 2, pp. 137-142, June 2008.

[6] http://www.odec.ca

[7]Adel A Elbaset Mohammed, " Study of Interconnecting Issues of Photovoltaic/Wind Hybrid System with Electric Utility Using Artificial Intelligence ", Ph. D. Thesis, Faculty of Eng.